

# Topocluster & Jet Finding R&D Needs for Phase-II TDR



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***November 16, 2016***

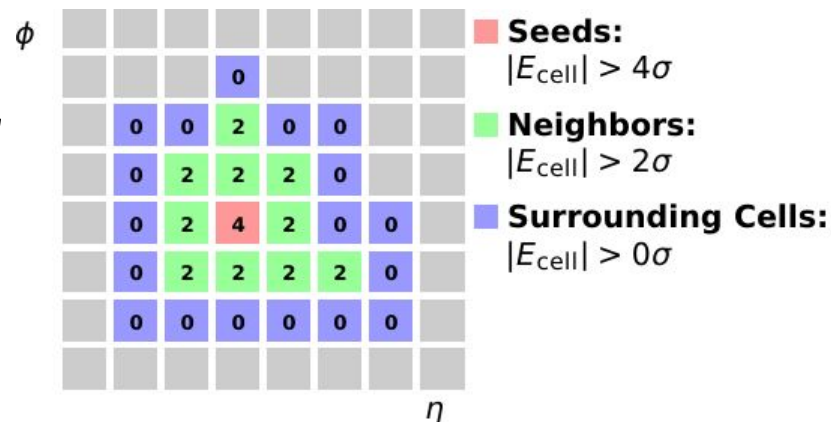
# Topological Clusters

- **Jets, taus, &  $E_T^{miss}$  are constructed from “topological clusters”**

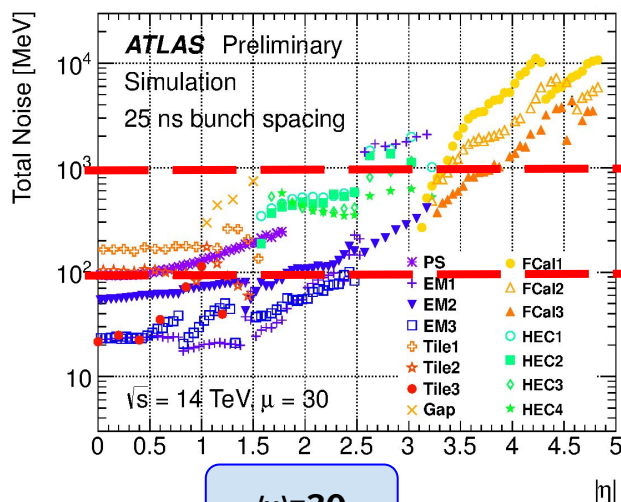
- 3D blobs of neighboring calorimeter cells surrounding a seed cell

- **Clustering based on energy significance,  $|E|/\sigma$ , per cell**

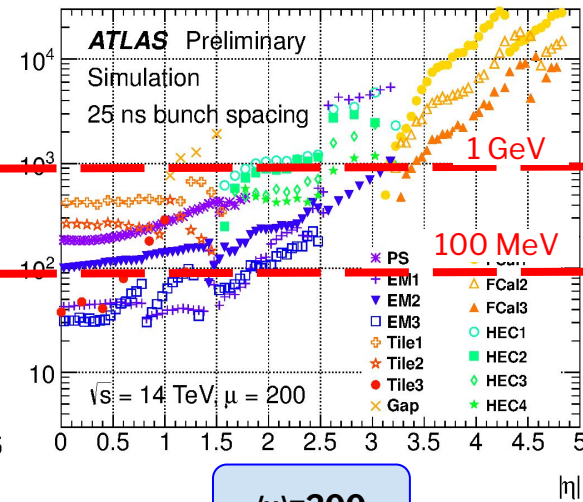
- $\sigma$  is sum-in-quadrature of electronic & expected pile-up noise defined per cell
- suppresses some noise contributions



**Excellent description:**  
<https://arxiv.org/abs/1603.02934>

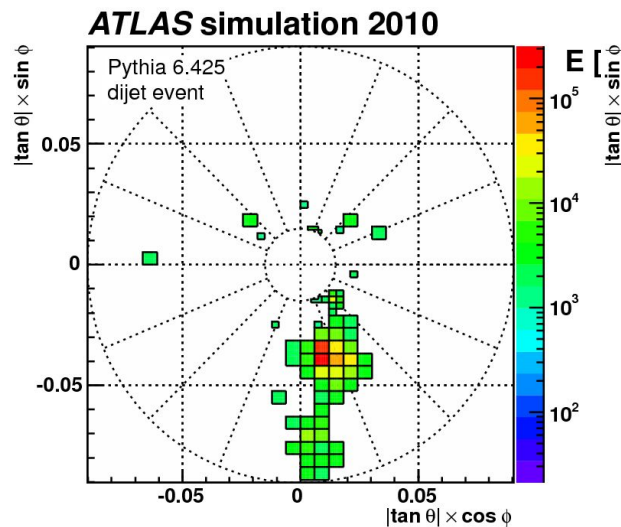


$\langle\mu\rangle=30$



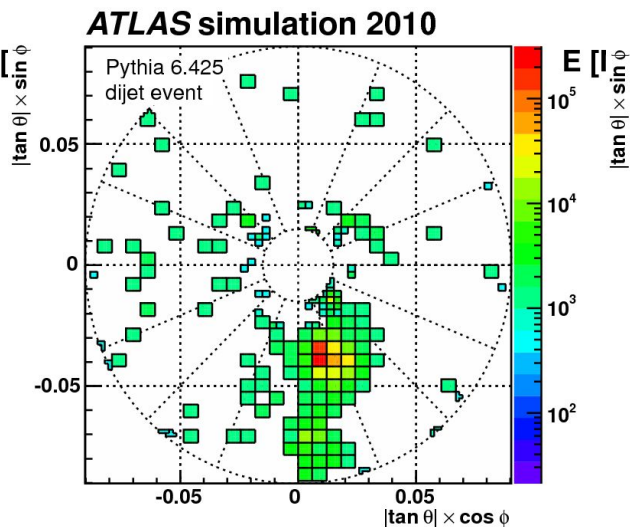
$\langle\mu\rangle=200$

# Topological Clusters



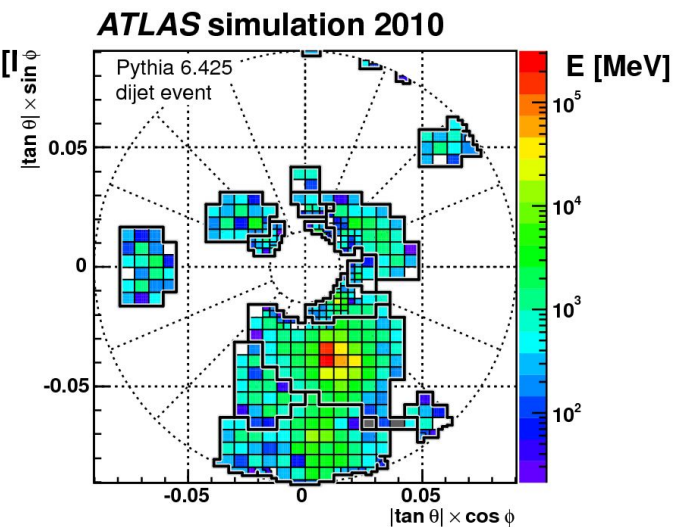
**Seeds**

$$|E_{\text{cell}}| > 4\sigma$$



**Neighbors**

$$|E_{\text{cell}}| > 2\sigma$$



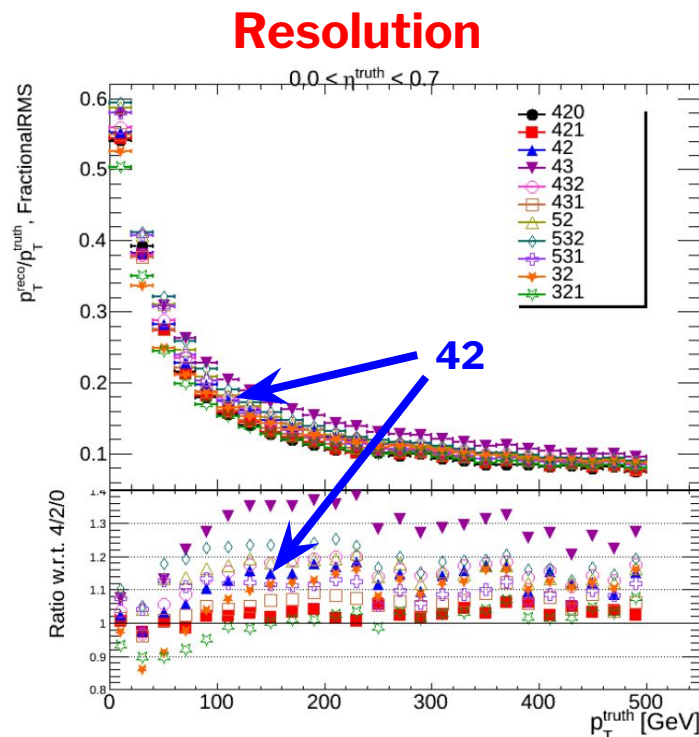
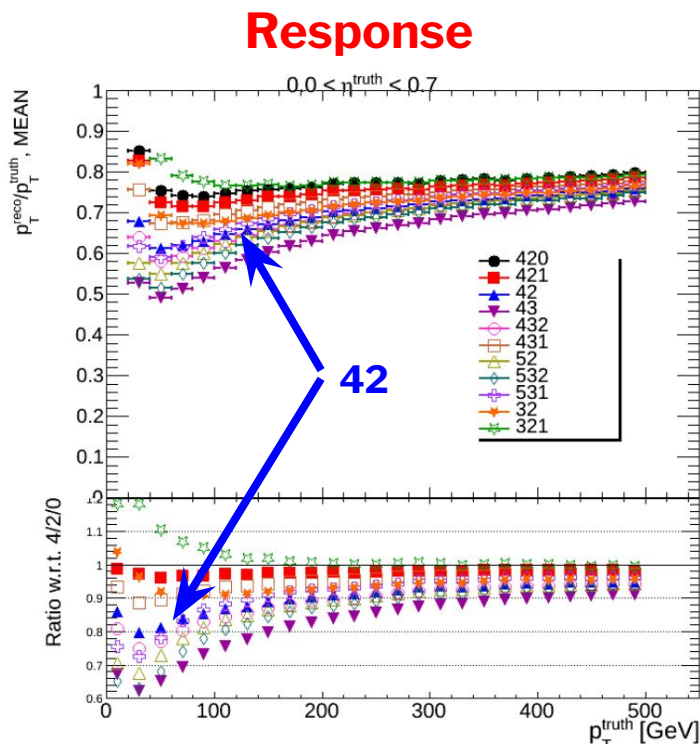
**Surrounding**

[final clusters]

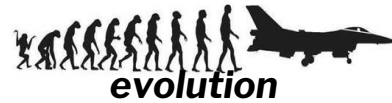
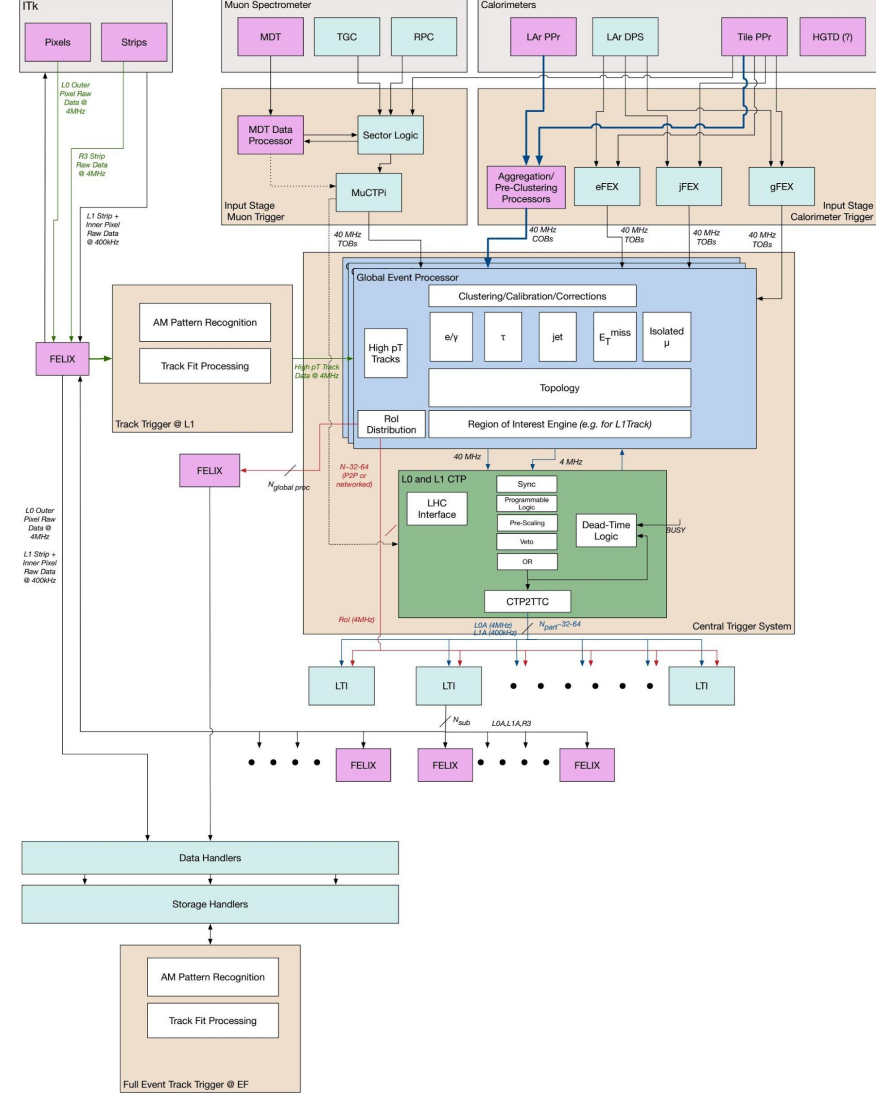
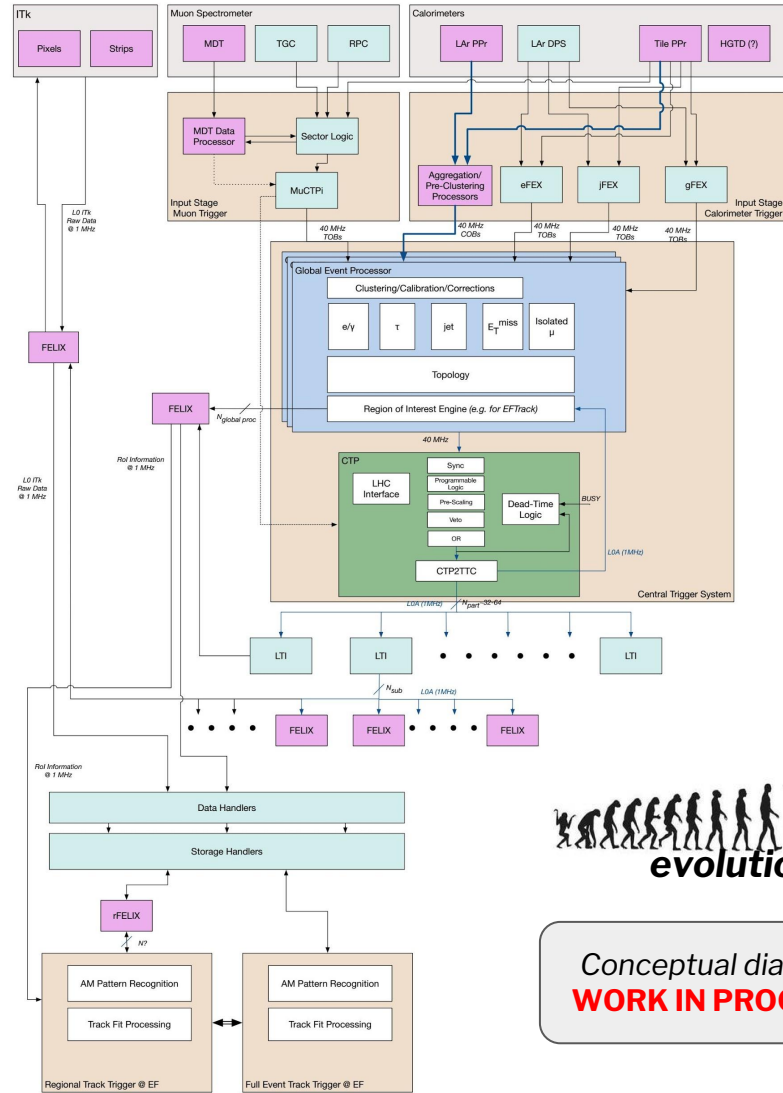
*Need to study impact of surrounding cells on object performance!*

# Topocluster Significance Threshold Choices

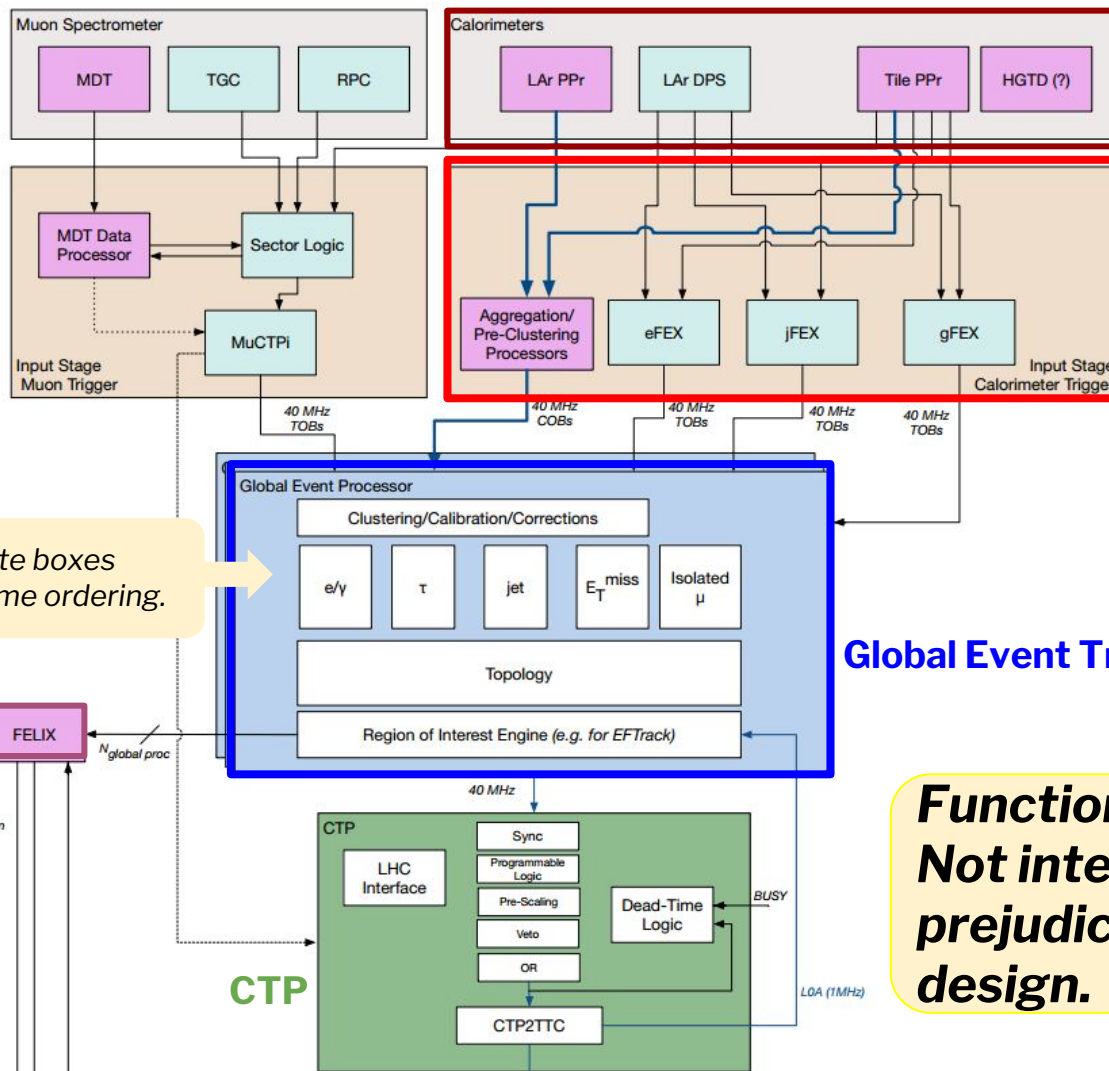
- **Offline uses 420 significance thresholds**
  - using 42 — excluding boundary cells — reduces jet response and resolution by ~15%



[https://indico.cern.ch/event/342054/contribution/0/attachments/672188/923782/ClusteringStudies\\_3SIGMA.pdf](https://indico.cern.ch/event/342054/contribution/0/attachments/672188/923782/ClusteringStudies_3SIGMA.pdf)



Conceptual diagrams  
**WORK IN PROGRESS**



**Calorimeter  
DPS & PPr**

**L0Calo**

**Global Event Trigger Processing System**

Organization of white boxes  
does not indicate time ordering.

**Functional diagram only!  
Not intended to  
prejudice the hardware  
design.**

# Topoclustering Questions

- **Granularity**

- cells,  $0.025 \times 0.025$ , supercells, ...?
- increased granularity for some layers (EM1, FCAL)
- zero suppression (needs cell ID)
- 420 vs. 42

- **PPr → Aggregator/cFEX → Global**

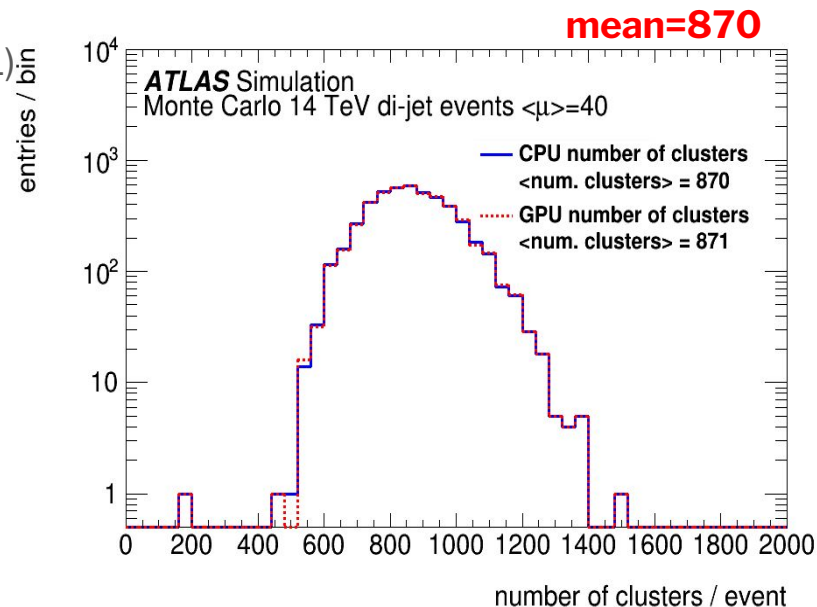
- **assume 1780 fibers**: 1524 LAr + 256 Tile
- final fiber count depends on rate (4-40 MHz), transmission speed (10-40 Gb/s), granularity, data quantities, digitization, etc

- **Latency to form topoclusters?**

- including data prep. & calibrations
- **fits within ~5 BC??**

- **Transmit all topoclusters?**

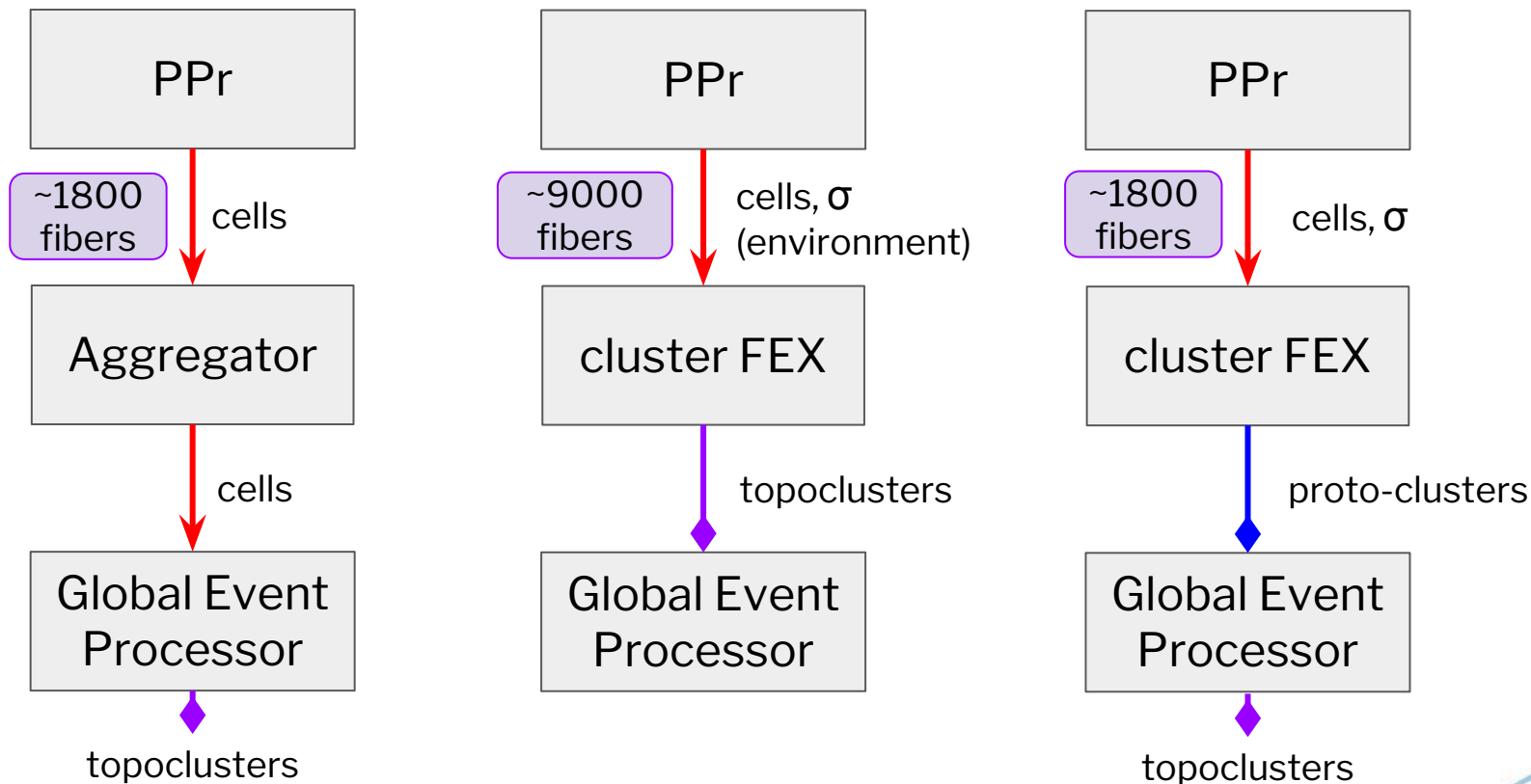
- $\mathcal{O}(1000)$  topoclusters per event
  - with optimal  $\mu$ -threshold choice
  - reduce with minimum  $E_T$  cut → impact on object performance?
- X-bits of  $E_T$ ,  $\eta$ ,  $\phi$ , depth. Moments? LC weights?



$\langle\mu\rangle=40$

# Constructing Topoclusters

*Where topoclusters are built depends on bandwidth, resources, and latency*



# Constructing Topoclusters

## LASP:

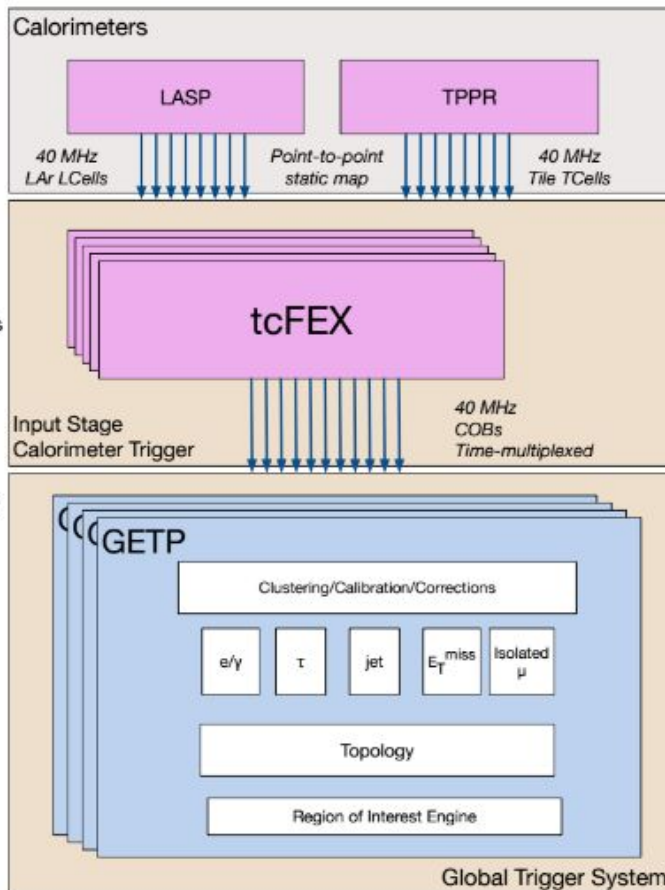
- Input Raw Data
- Energy Reconstruction
- LCell Aggregation:
  - fixed granularity data, no-zero suppression
  - List of cluster-position/type in EM1 (e.g. Eratio-like data with address)

## tcFEX:

- Second-stage of Aggregation/
- Partial Topo-cluster Processing - COBs

## GETP: Global Event Trigger Processor

- Input functional block includes:
  - Third-stage of Aggregation/
  - Complete Topo-cluster Finders (i.e. COBs or merged COBs)
  - Calibration
  - Correction



## TPPR:

- Input Raw Data
- Energy Reconstruction
- TCell Aggregation:
  - fixed granularity data, no-zero suppression
  - Any hadronic-based moment?

## COB:

- Topo-cluster (if contained in a single tcFEX module) object (ET, eta, phi, ... other moments)
- OR
- Partial topo-cluster + list of 2-sigma energies/position of the L/T-cells at the tcFEX module boundary

# Aggregator/cFEX & Global Event Processor

- **Topocluster-based isolation?**

- $e/\gamma, \mu, \tau$
- mini-isolation

- **Tower vs. topocluster  $E_T^{\text{miss}}$**

- pileup suppression?

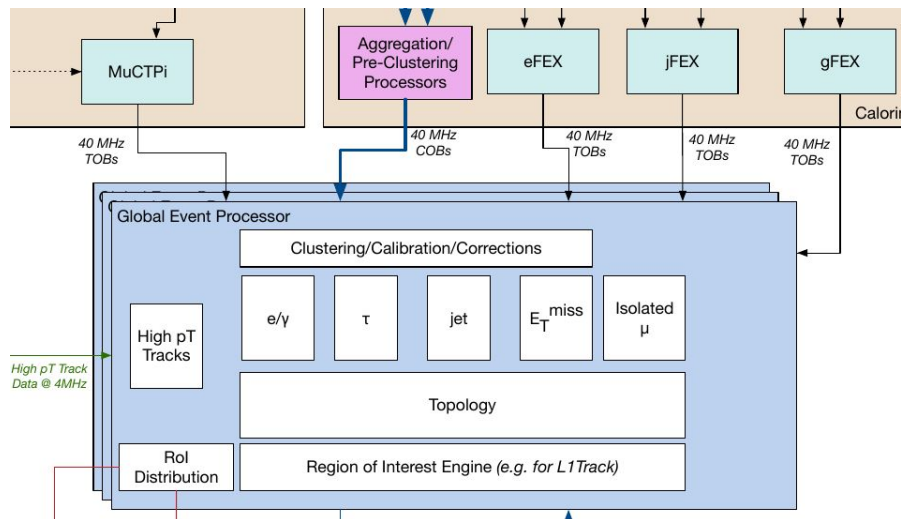
- ***Tau identification***

- **Topocluster-based anti- $k_T$  jets**

- achieve  $<10 \mu\text{s}$  latency?
- impact of limited iterations
- impact of topocluster choices (42 vs. 420,  $E_T$  cut)
- what technologies are viable?
- primarily useful for complex environments  
→ *sufficient justification?*

- **Track-topocluster matches**

- Cluster vertex fraction?
  - $p_T > 4 \text{ GeV}$  too high!



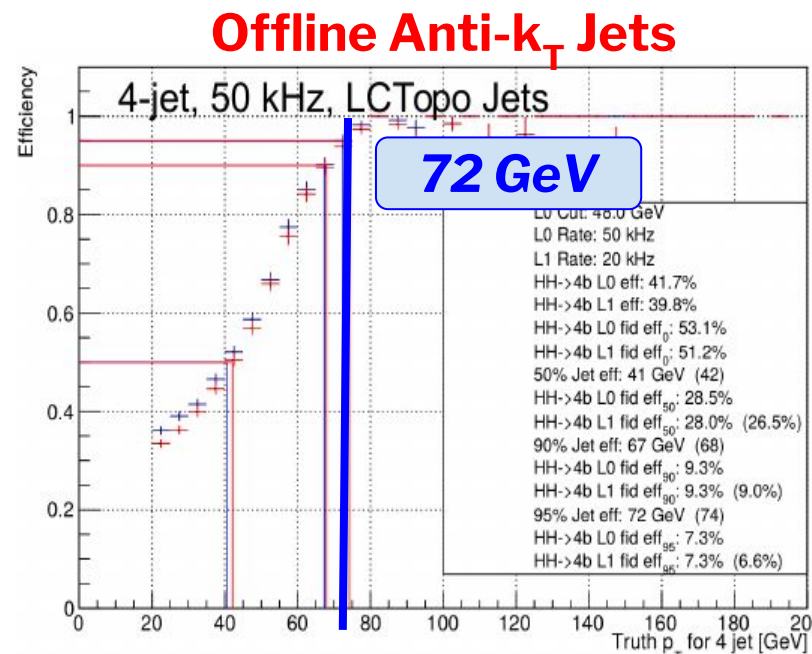
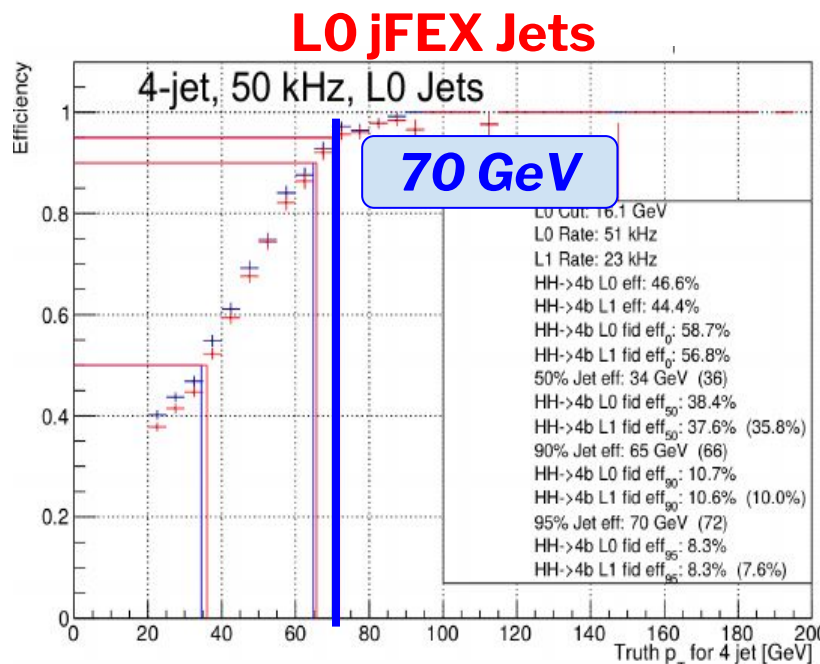
**Tracking & HGTD?  
pFlow-lite?**

# Trigger Jets vs Offline Jets

- **Event configurations with well-separated jets have no significant differences in efficiency or rate between Towers & Topoclusters**

- HH  $\rightarrow$  bbbb trigger studies by Brian Petersen

<https://indico.cern.ch/event/579495/contributions/2348142/attachments/1360954/2059386/jFexStudies-2016-10-17.pdf>



# Jets in Crowded Environments

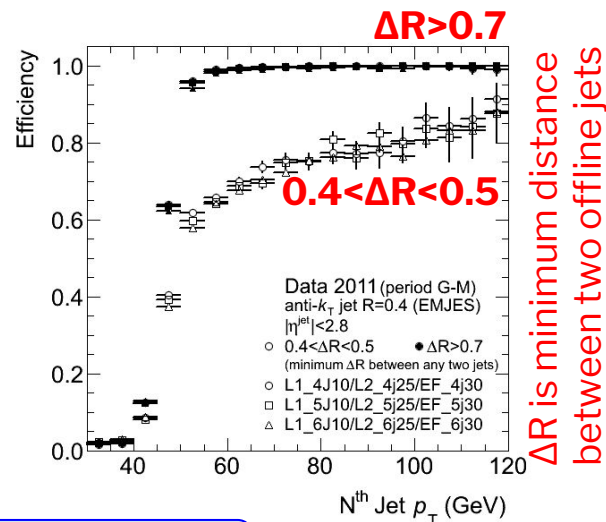
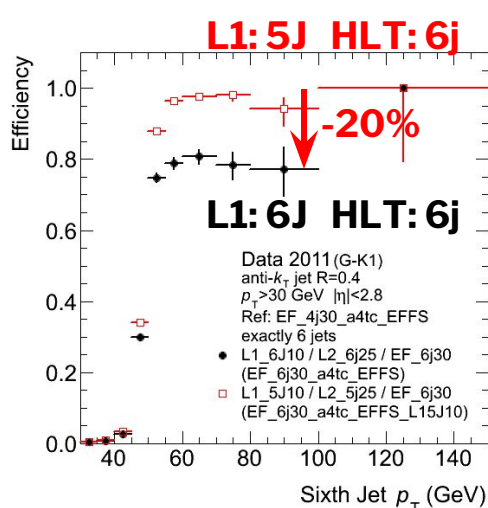
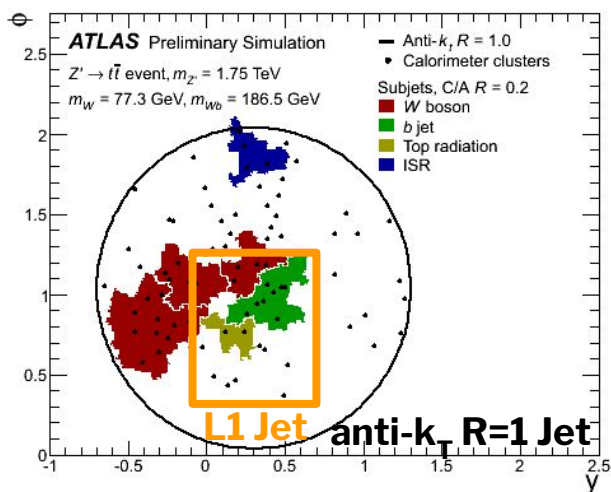
- **Difficult to distinguish multiple closely-spaced jets**

- events with large jet multiplicities or presence of Lorentz-boosted objects (+pileup!)

- *offline jet boundaries determined by  $k_T$  algorithms using topocluster inputs*

- utilizing different algorithms online can lead to inefficient triggers

➤ *local maximum requirement in L0 trigger jet algorithm misses events with close-by jets*

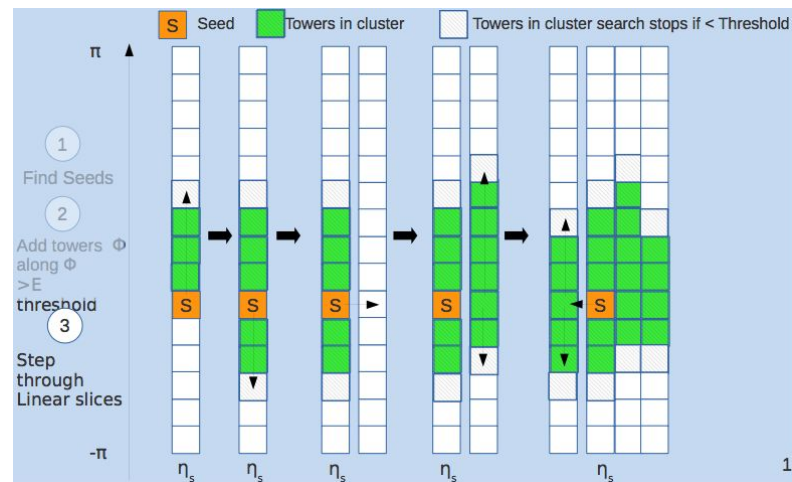


Results from Run 1

# Current R&D Activities

- **Topocluster-inspired algorithm on FPGA**
  - MSU & Oregon
- **Simulation performance for clustering algos**
  - Oregon
- **Topoclustering with supercells**
  - MSU
- **Softkiller pileup suppression**
  - Harvard
- **Parallelization for GPU**
  - LTU
- **Jet-finding with different granularities**
  - Indiana
- **Tau identification**
  - Oregon
- **Planned activities:**
  - hadronic reconstruction (Chicago)
  - track-based pileup suppression (Pittsburgh)

Apologies if I didn't include your group's activities!



# Conclusions

- **The use of topoclusters influences the Trigger Architecture**

- where are topoclusters built?
- how is the information transmitted?
- what is impact on L0 and L1 accepts? ROIs?
- what level of rejection is possible?



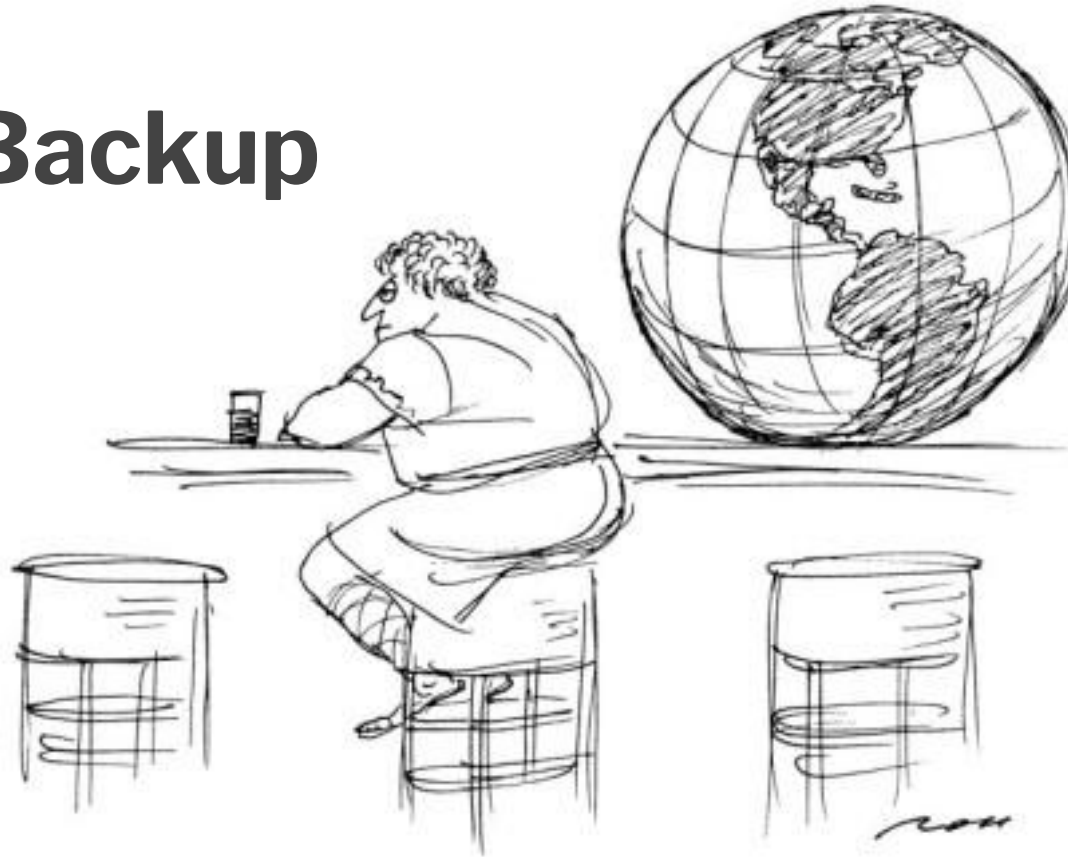
*"I can't believe I didn't think of this before."*

- **Crucial to accomplish early in TDR timeline!**

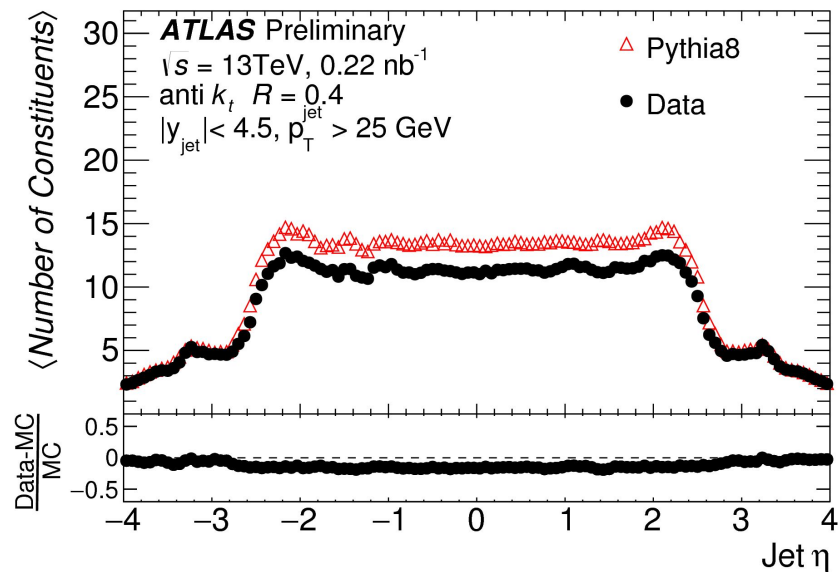
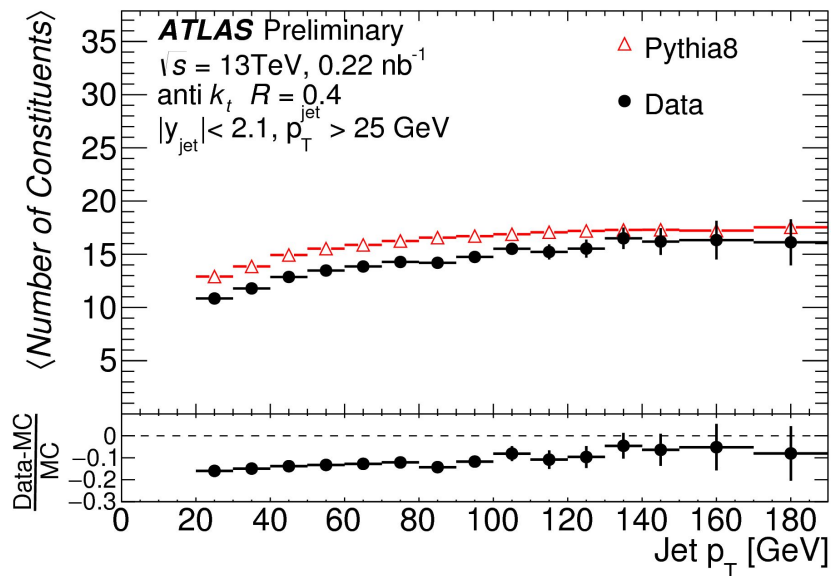
- **Needs common tools to leverage on-going studies**

- xAOD collections of topoclusters with different granularities and thresholds
- simple trigger algorithms: isolation, jets,  $E_T^{\text{miss}}$ , etc
- calibrations
- coordinated effort

# Backup

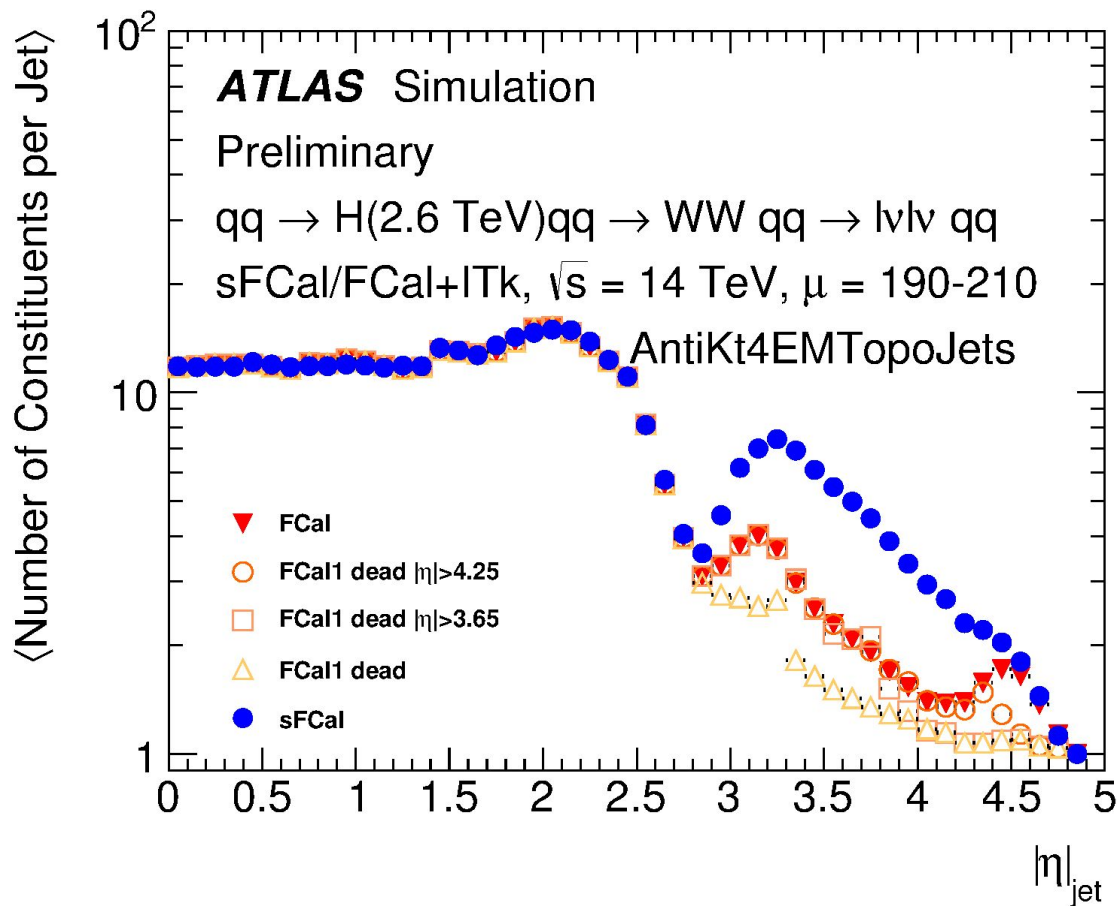


# Topoclusters per Jet (2015)

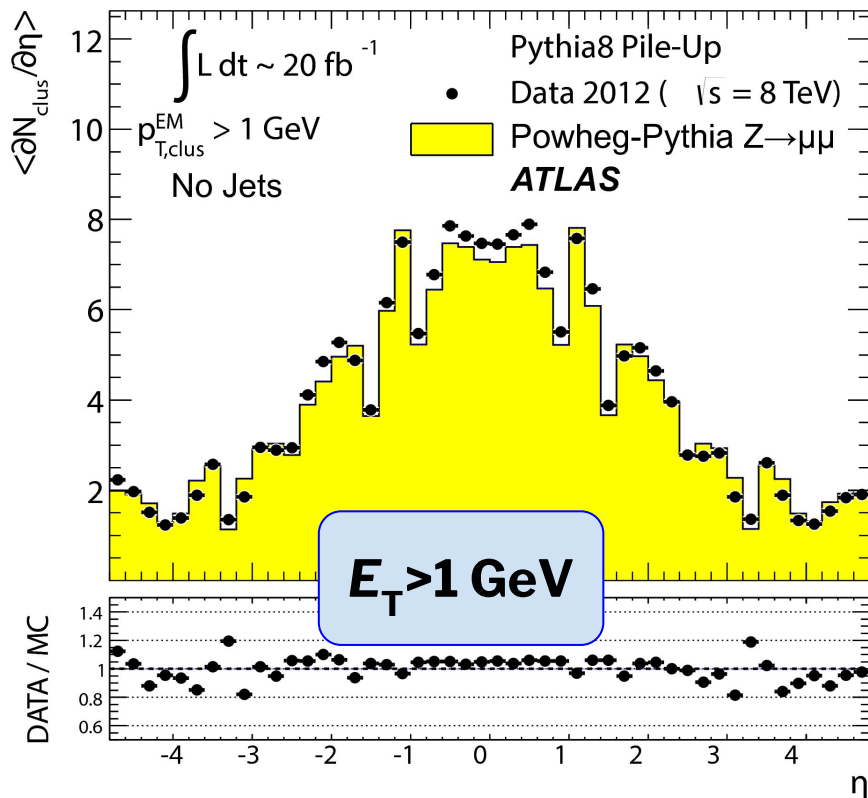
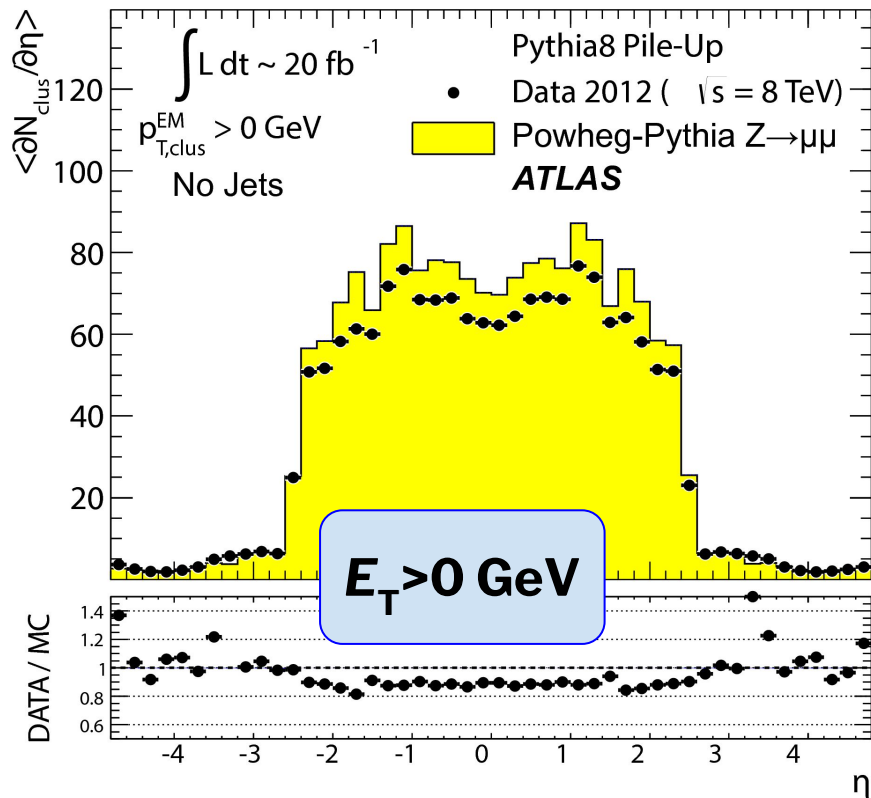


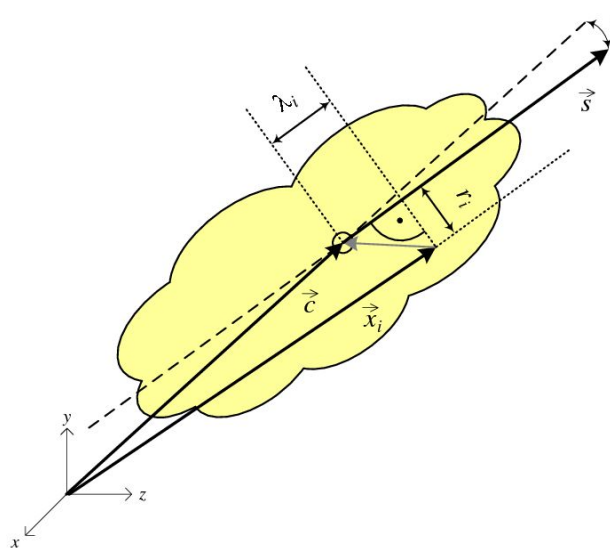
$\langle \mu \rangle = 20$

# Topocluster Density Per Jet (HL-LHC)



# Pile-up Topocluster Density (2012)





$\vec{c}$  centre of gravity of cluster, measured from the nominal vertex ( $x = 0, y = 0, z = 0$ ) in ATLAS

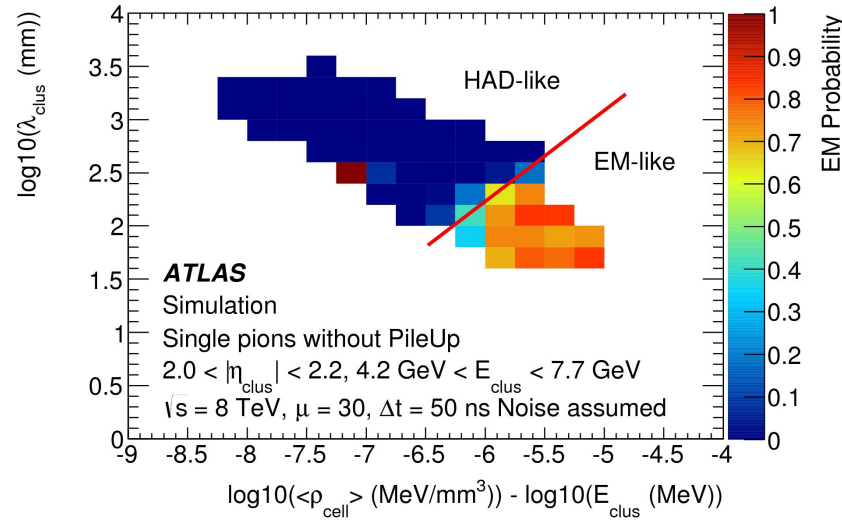
$\vec{x}_i$  geometrical centre of a calorimeter cell in the cluster, measured from the nominal detector centre of ATLAS

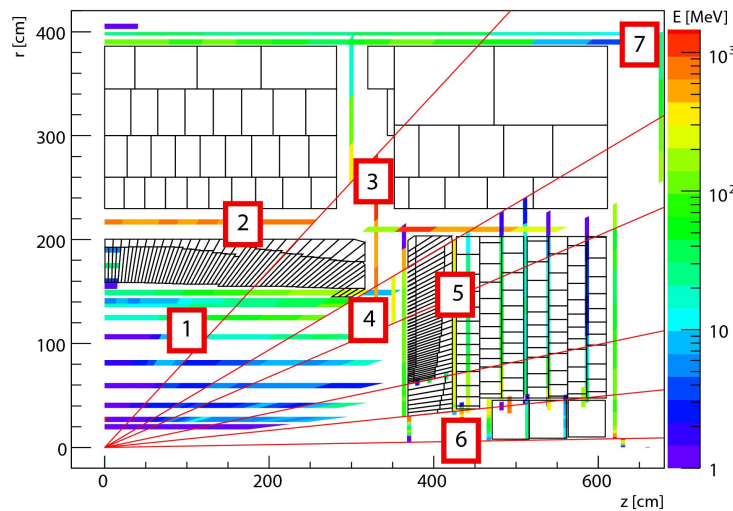
$\vec{s}$  particle direction of flight (shower axis)

$\Delta\alpha$  angular distance  $\Delta\alpha = \angle(\vec{c}, \vec{s})$  between cluster centre of gravity and shower axis  $\vec{s}$

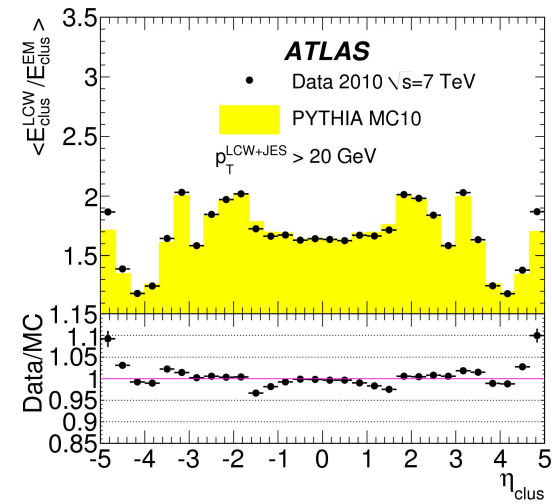
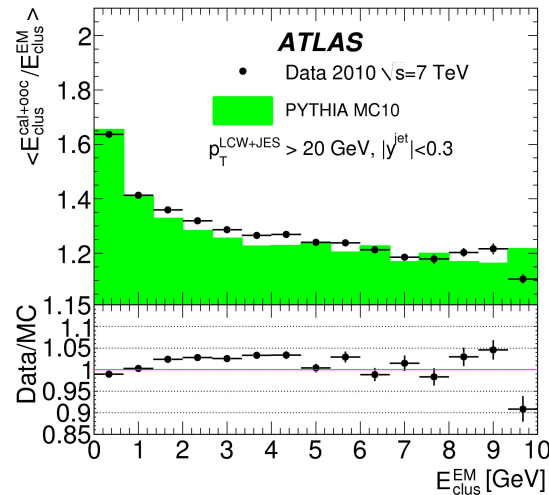
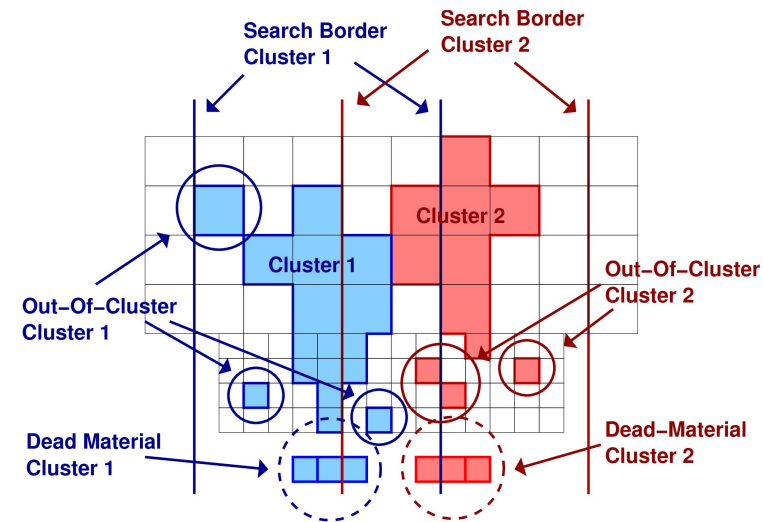
$\lambda_i$  distance of cell at  $\vec{x}_i$  from the cluster centre of gravity measured along shower axis  $\vec{s}$  ( $\lambda_i < 0$  is possible)

$r_i$  radial (shortest) distance of cell at  $\vec{x}_i$  from shower axis  $\vec{s}$  ( $r_i \geq 0$ )

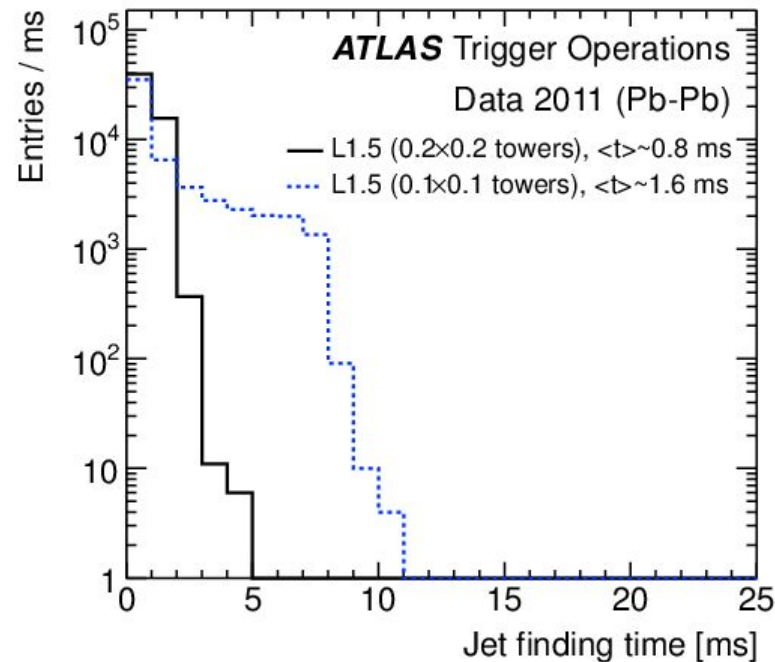
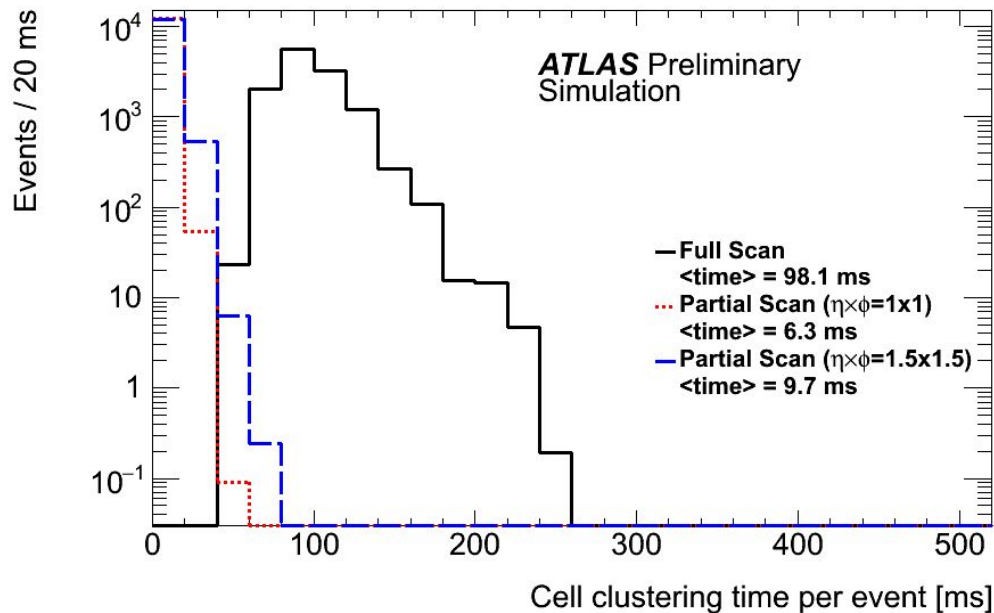




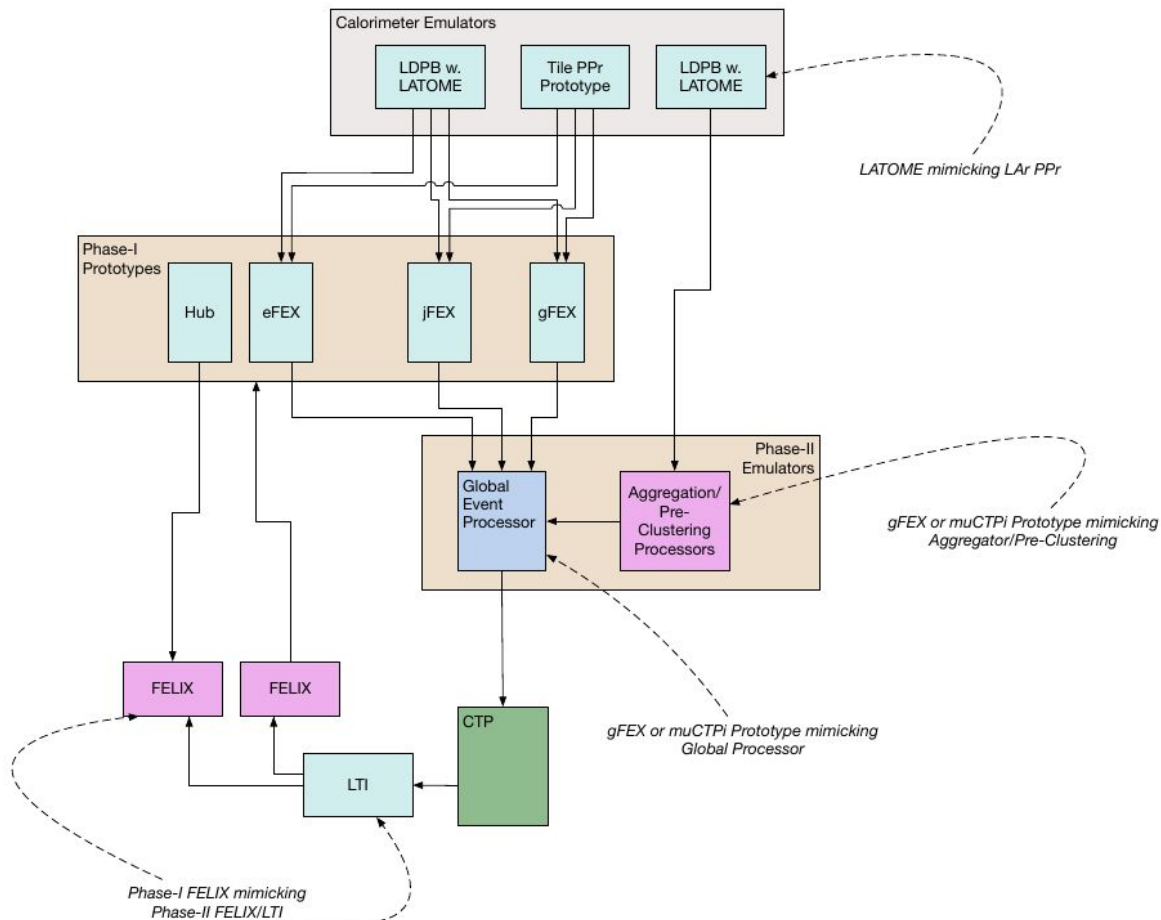
Regions	Description	Cluster signals for dead material correction
1	In front of EMB	Energy in PreSamplerB
2	Between EMB and Tile	Energies in last layer of EMB and first layer of Tile
3	In front of Tile gap scintillators	Energy in Tile gap scintillators
4	In front of EMEC	Energy in PreSamplerE
5	Between EMEC and HEC	Energies in last layer of EMEC and first layer of HEC
6	In front of FCAL	Energy in first FCAL module
7	Behind calorimeters	Energy in last layer of hadronic calorimeters and $\mathcal{D}_{clus}^{dm}$ given in Eq. (25)
8	Everywhere else	



# Time to Reconstruct Clusters & Jets in HLT



# Phase-II Demonstration System



- **Refine design requirements**

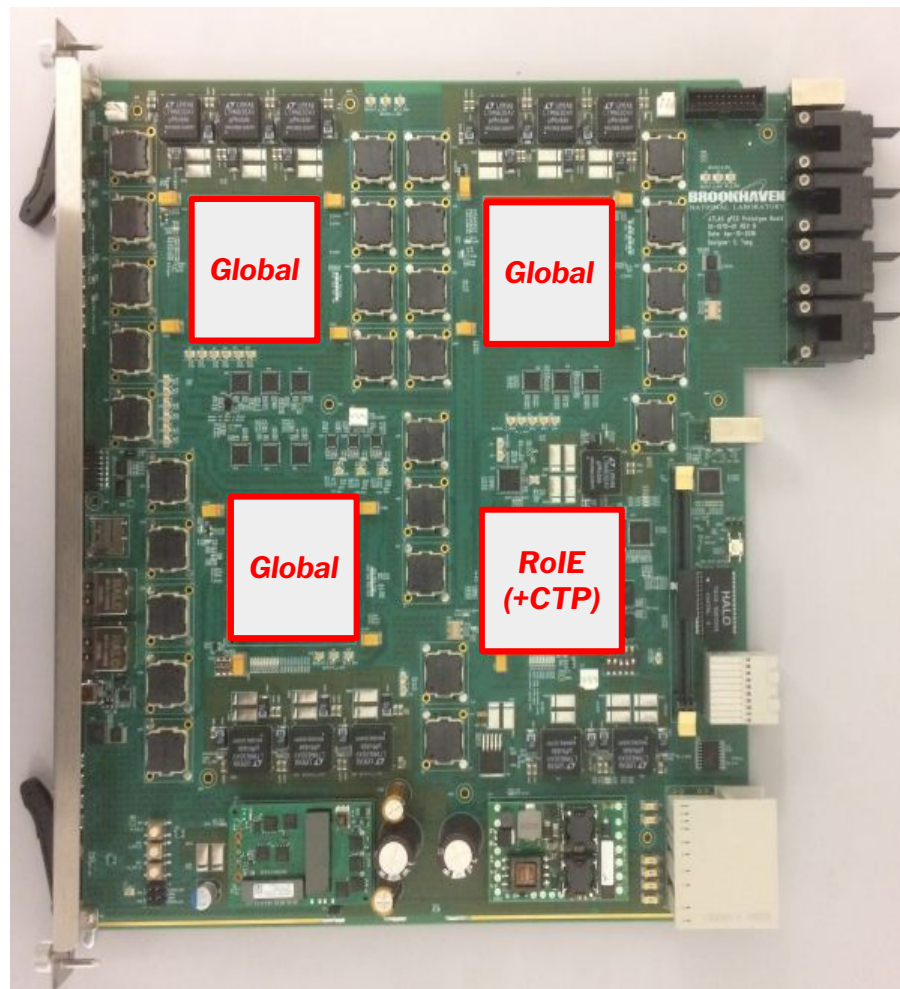
- input from Calo & Muon
- output to CTP/LTI/FELIX or combine CTP functions on same module

- **Time-multiplexed demonstrator test stand can be built at CERN**

- start from Calo FEX modules
- exercise data flow & trigger path through Global/CTP/RoIE, CTP, LTI, FELIX, etc

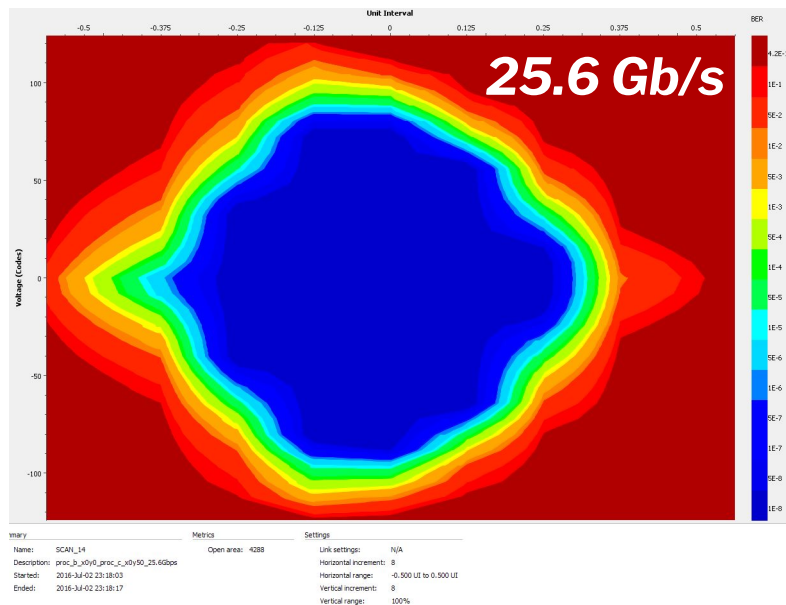
# gFEX Prototype

- **Existing module**
  - 3 Virtex Ultrascale FPGA
  - 1 ZYNQ SoC
  - many miniPODs for optical communications
- **MGT Links**
  - 12.8 Gb/s & 25.6 Gb/s
- **Inter-FPGA communications**
  - 40-bit parallel bus running at 560 MHz  
DDR → 1.1 Gb/s
- **Pre-Production module features**  
**Zynq Ultrascale+ FPGA**
  - improved processing capability



# Evaluation of Key Technologies

- **High-speed optical links will be evaluated in coming months**
  - 25.6 Gb/s on-board links have been successfully demonstrated on the gFEX prototype
  - next step is to evaluate 25+ Gb/s parallel optical links
  - *important step in evaluating feasibility of Global Event Processor conceptual designs*



**Samtec Firefly**